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(71) Applicants
Patrick Joseph Newell, Department of Microbiology, University College, Galway, Republic of Ireland. Lawrence Kieran Dunican, Department of Microbiology, University College, Galway, Republic of Ireland. John Joseph Sweeney, Main Street, Loughrea, County Galway, Republic of Ireland
(72) Inventors
Patrick Joseph Newell,
Lawrence Kieran Dunican,
John Joseph Sweeney
(74) Agents
Tomkins & Co

(54) **Anaerobic treatment of waste to produce methane**

(57) The invention relates to a method for treating waste products in particular animal manure slurries to produce methane. In the method of the invention acidification and methanogenesis is carried out in two separate stages and in separate containers. The slurry is first held in a holding tank to allow acidification to occur and a liquid fraction comprising the volatile acids produced is separated from a solids fraction. The liquid fraction is then passed to an anaerobic digester in which the methane bacteria is supported by a holding matrix. The invention also includes apparatus for use in the method comprising a holding tank in which acidification of the slurry occurs, means for separating the liquid and solids fractions of the slurry, means for feeding the liquid fraction to the digester which contains the holding matrix, and means for removing methane and residual effluent from the digester.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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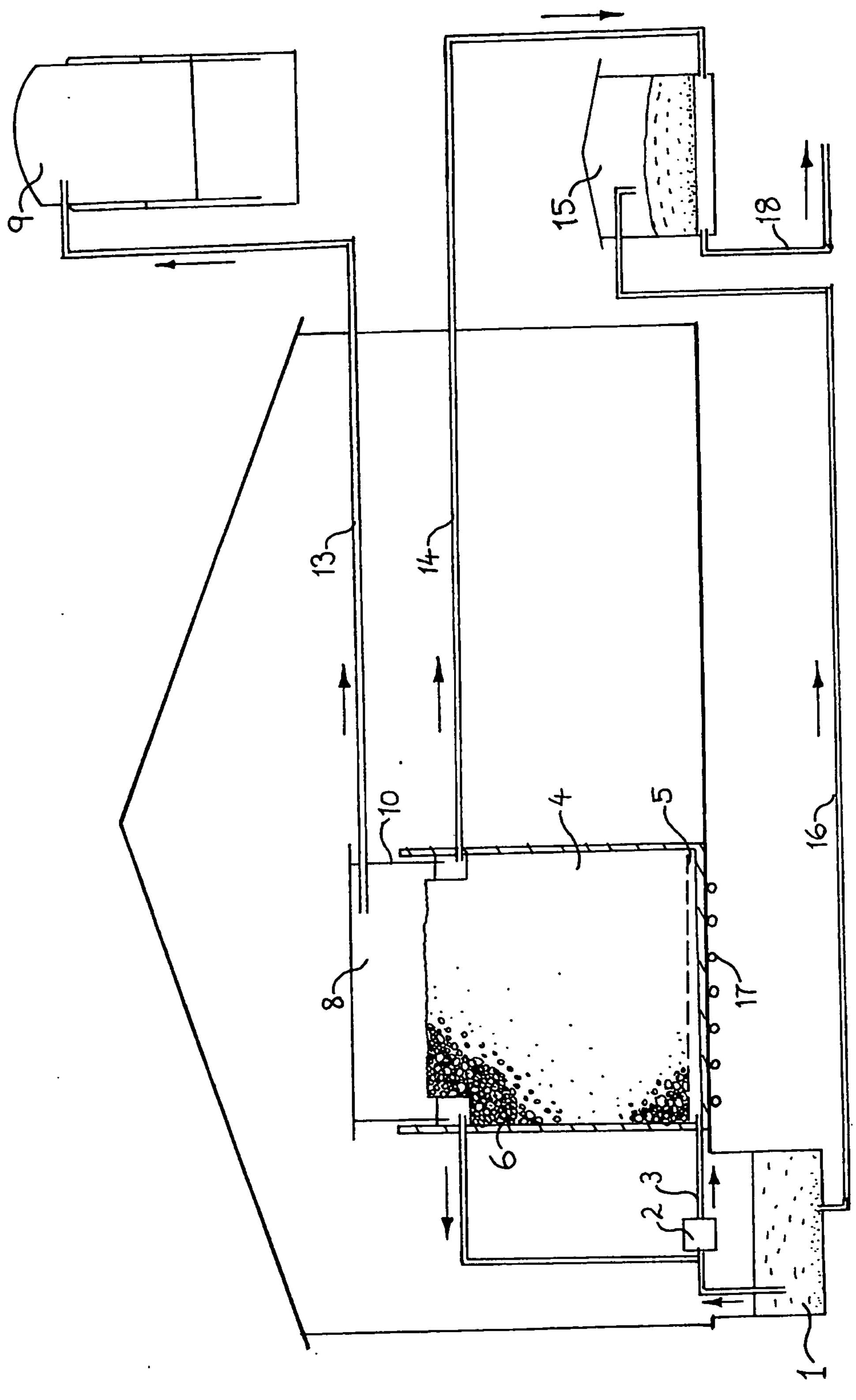

Fig. 1.

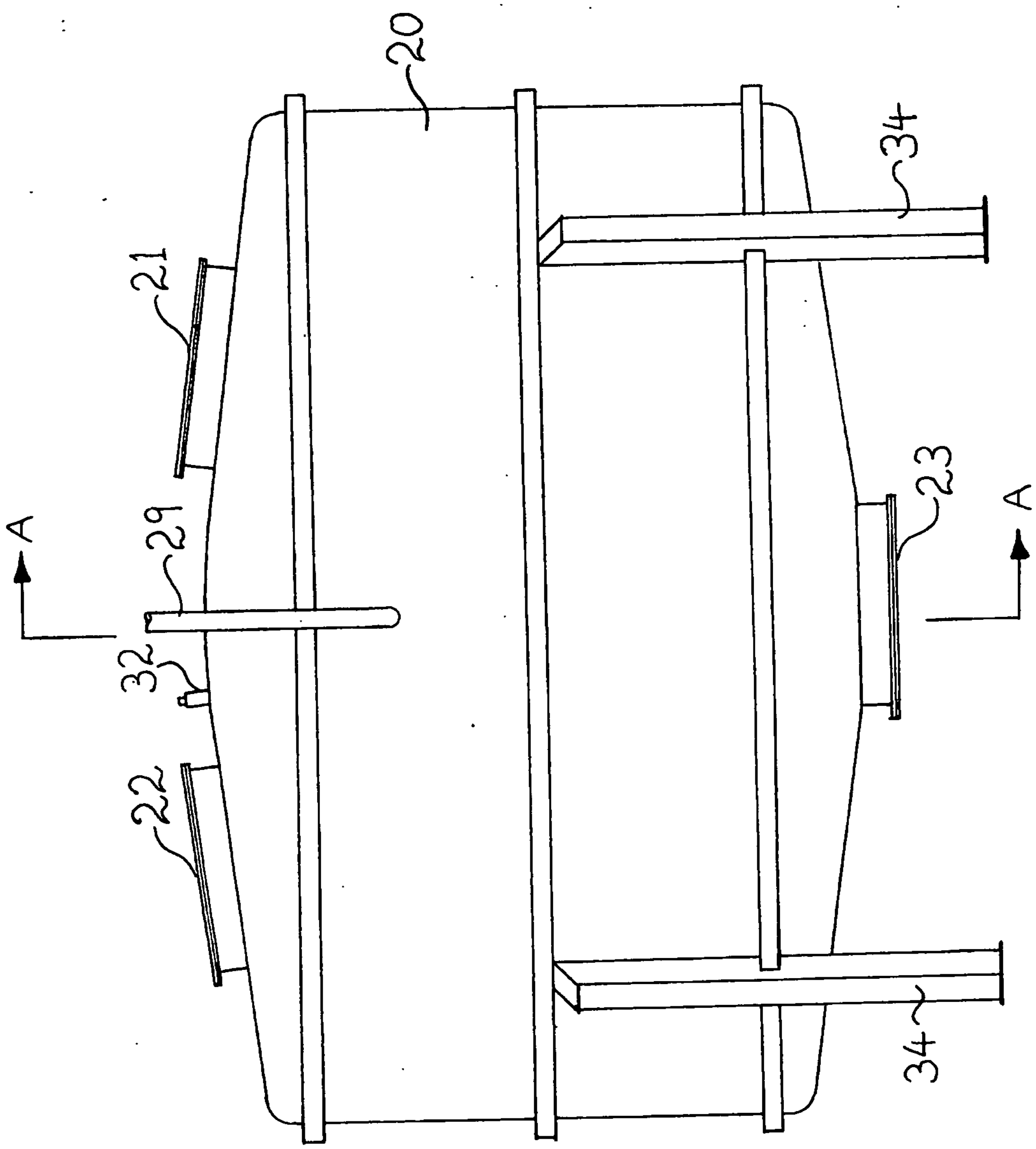

Fig 2

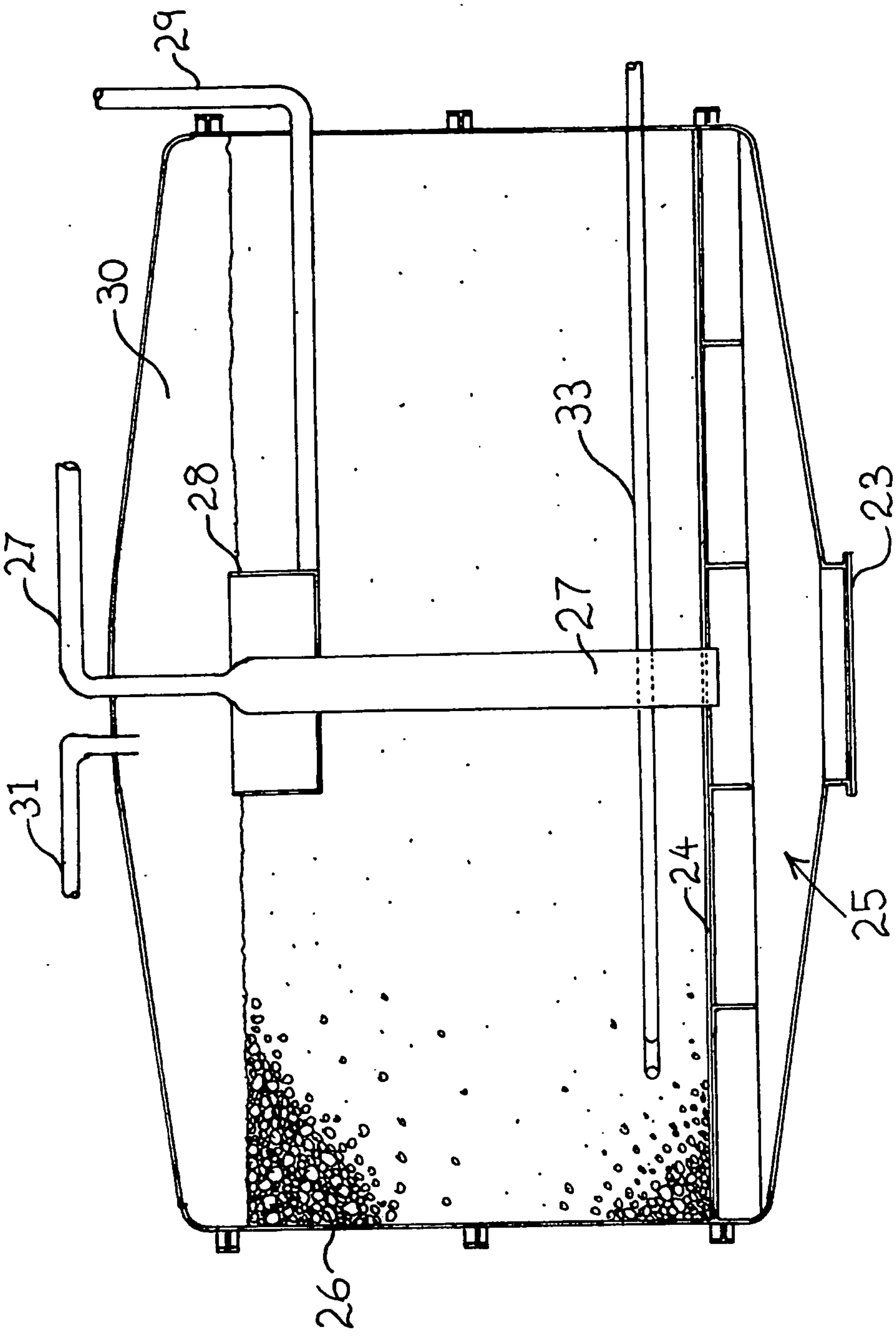

Fig. 3

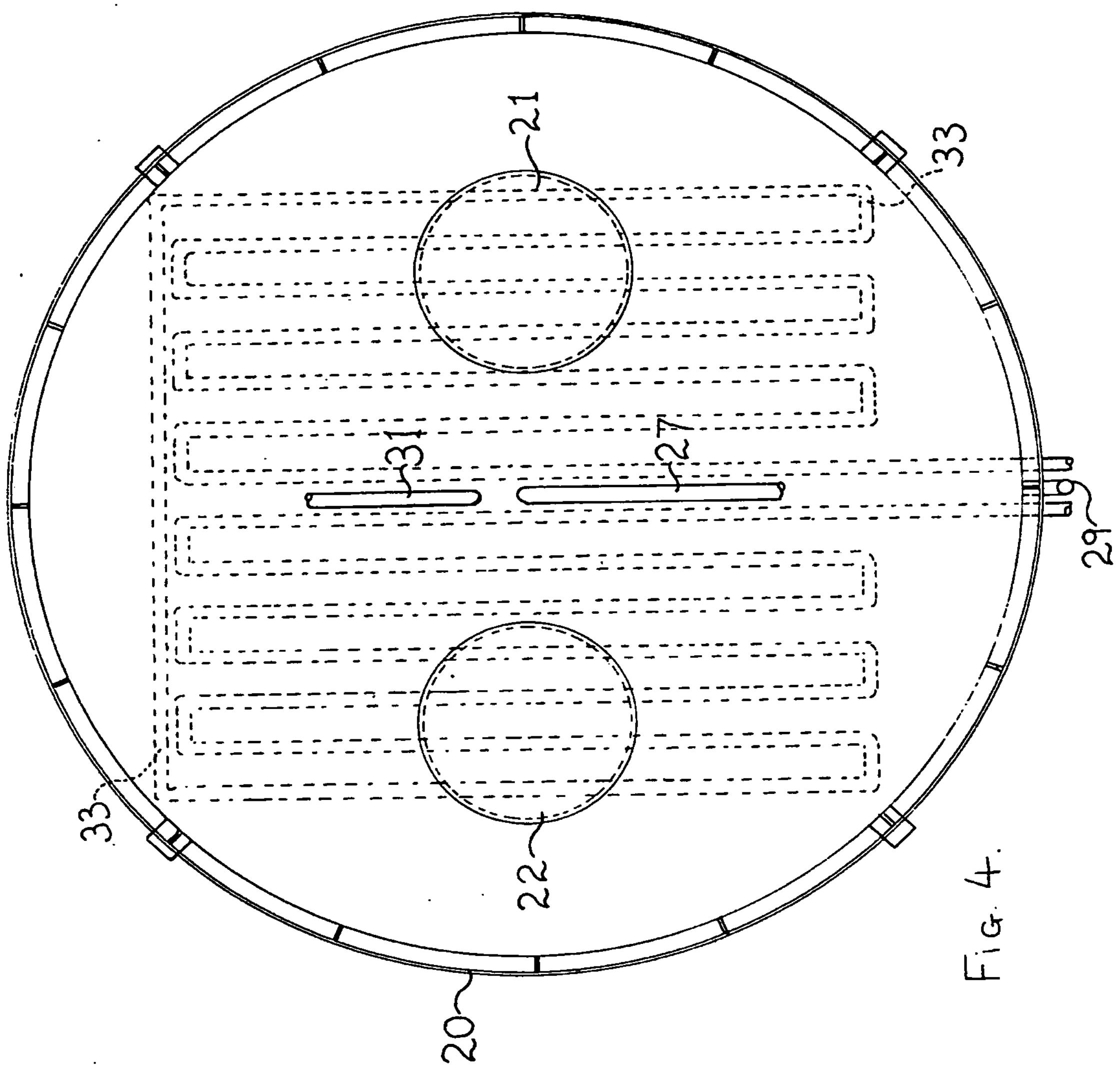

Fig. 4.

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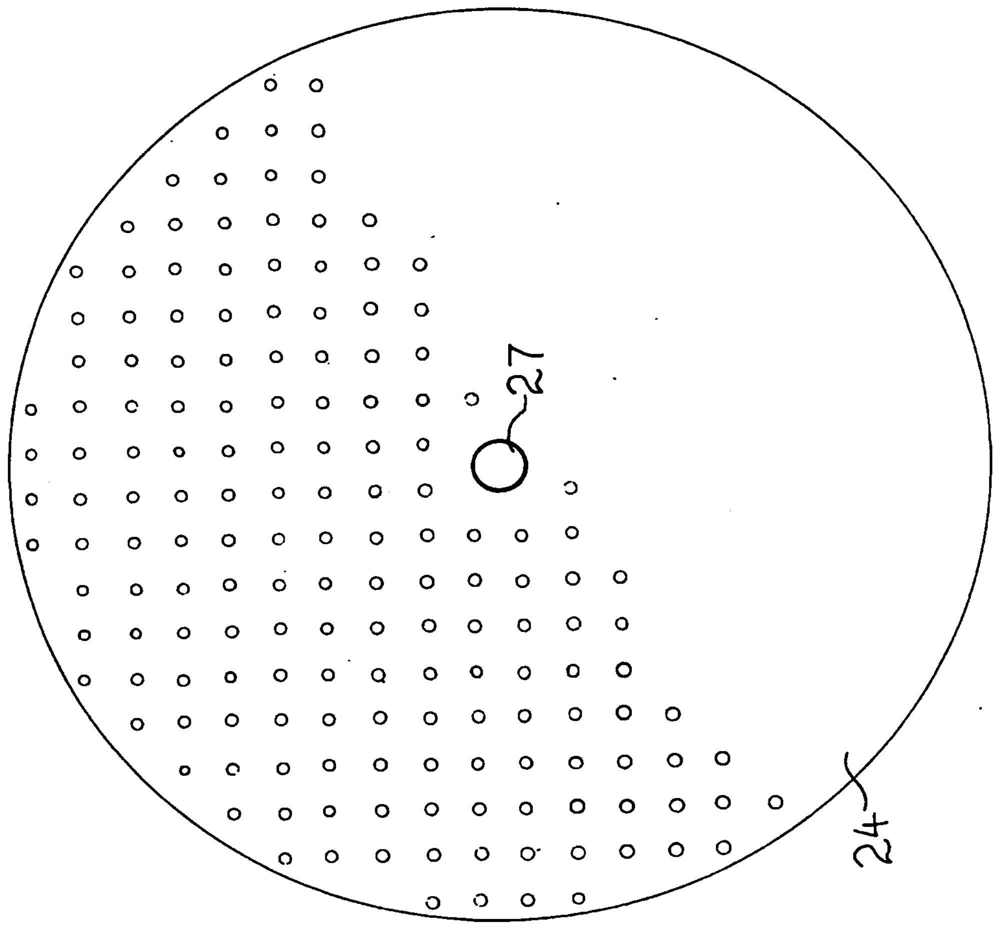

Fig. 5

SPECIFICATION

A method and apparatus for treating waste products

The present invention relates to a method and apparatus for treating waste products such as animal manures, and to a method and apparatus for the production of methane.

The disposal of farm wastes has become an acute problem especially in relation to intensive farm units. The polluting potential of animal wastes is considerable. The current farm animal population represents a pollution potential which greatly exceeds that due to the human population. Known methods for the disposal of farm wastes include land spreading, aerobic treatment and some anaerobic systems. Land spreading involves spreading the manure as a slurry or a semi-solid on agricultural land, mainly on grassland. The amount of slurry which can be spread on land depends on the hydraulic properties of the soil, rainfall, strength of the effluent, etc. Most soils are too wet to receive slurry from October to April and slurry must be stored during this period. At least a 20,000 gallon tank would be required for this purpose in the case of the slurry from a 100 pig unit. Five acres of land would be required in order to spread this slurry. Land requirements are therefore high (10,000 pig units require at least 500 acres) and often pig producers have either insufficient land, or the soil is hydraulically unsuitable for land spreading. Land spreading may have the additional problems of the build-up of heavy metals in soil, the build-up of nitrates in soil and drainage and the spread of disease producing bacteria, e.g. *Salmonella*.

While many of the sophisticated aerobic treatment systems used in municipal and industrial sewage treatment may be used for farm wastes, their costs are prohibitive. 90% removal of BOD can be achieved by aerobic treatment. However, since the initial BOD of farm wastes is so high (21,500 mg/L) the 2,150 mg/L remaining after treatment is still too potent to release into streams. Royal Commission Standards which are suggested levels tolerable in Ireland only permit effluents of 20 mg/L BOD or less to be discharged into waterways where dilution of 1 in 8 occurs. Anaerobic systems which chiefly mean holding the material in the absence of oxygen for several months reduce BOD by only 20 to 30%. Furthermore, with both of the systems the treated effluent must still be spread on land. Aerobic lagoons may be used in areas where large shallow ponds are built and where temperature and light are sufficient to give good algal growth. However, the method requires excessive areas of land for the ponds and is impractical in Ireland.

The treatment of wastes by methane-producing processes are known especially in relation to town sewage-treatment plants. However, the efficiency of such plants in the production of methane is low, and even high-rate plants run on a 10 to 12 day, or longer, slurry retention time. As a result of the long retention time very large digester units are required and these would be uneconomical for use with farm waste where it is desired to treat the waste on the farm. With short retention times a slight change in the feed of the reactor results in failure of the plant.

One method of reducing the retention time in the digester is to use an anaerobic filter as the digester. This involves the retention of the active biological floc in the digester through attachment to a solid holding matrix such as gravel. Depending on the biodegradability of the effluent, retention times of less than one day can be achieved. In using the anaerobic filter raw effluent is passed into the base of the digester and is caused to flow upwards through the holding media. The active anaerobic bacteria growth attached to the solids and the polluting organic substrate is removed from the liquid as it passes over the solids. The gas and liquid phases readily separate at the top of the digester. As a result of the low growth rate of the anaerobic bacteria, there is only a very small amount of biological solids production in the digester, which means that the filter will not become clogged due to biological growth. However, a serious disadvantage associated with known methods of using anaerobic filters is the need for the raw effluent to contain less that 1% solids, and so the anaerobic filter has not hitherto been successfully used with animal wastes, for example pig slurry.

It is an object of the invention to overcome these disadvantages and to provide a method and apparatus for treating wastes to produce methane in which the retention time in the digester is reduced, and which is economically suitable for use on forms and in extensive livestock units and which is stable over a relatively wide range of feed, for example.

According to the invention, a method of treating waste products, particularly strong organic waste such as animal slurries, to produce methane comprises:

1) holding the slurry for a period of time necessary to allow for the fermentation and conversion of the organic fraction of the slurry to volatile acids;

2) separating a liquid fraction containing said volatile acids from a solids fraction; and

3) feeding said liquid fraction containing said volatile acids into an anaerobic methane digester which contains a bacteria-holding matrix.

The temperature of the liquid fraction in the digester is maintained above ambient temperature, preferably at a temperature in the range 25°C to 35°C. A portion of the methane produced may be used to heat the reactor. With known methane digesters it is unknown to allow solids to separate out of solution before addition to the digester. However, in the method of the invention acidification and methanogenesis is carried out in two separate stages, and separation of the liquid and solids fraction takes place before addition of the liquid fraction to the digester. Known methane digesters have been

reported to become sour and fail when waste of strengths up to 20,000 mg/l as acetic acid have been added to them. The method of the invention works well even at this concentration without showing any ill effects. It is believed that this is because the bacteria which carry out the methanogenesis are protected from the toxic acids by reason of the fact that they develop a protective diffusion layer on attachment to the holding matrix in the digester. The method of the invention is stable at retention times down to 1 day or less on wastes as strong as 20,000 mg/l of acetic acid which is outside the range of any reported digester.

In carrying out the method of the invention the raw animal slurry, for example pig slurry, can be held in a tank or channel for up to a week at ambient temperatures. During this period conversion of the organic fraction of the slurry to volatile acids and liquefaction of volatile solids occurs. Simultaneously, the liquid fraction containing the volatile acids can be separated from the solids fraction by sedimentation. The supernatant liquor containing the volatile acids and any remaining suspended solids is then fed into the base of the anaerobic filter by plug flow or on a continuous or partly continuous basis. Alternatively, the solids fraction is separated from the liquid fraction by a mechanical separator.

The invention also includes apparatus for use in carrying out the method of the invention comprising holding means for the slurry in which fermentation of the slurry can occur and including means for separating the liquid fraction of the slurry from the solids fraction, means for feeding the liquid fraction to an anaerobic filter, said filter comprising a tank or the like containing a holding matrix for microbial flocs, and means for removing methane gas and residual effluent from the filter. Preferably, the anaerobic filter has an inlet for the liquid fraction at the bottom of the filter and has outlets at the top of the filter for methane gas and residual effluent. In one embodiment the tank has a floating cover which is adapted to rise to increase the volume of the digester as the methane is produced. The tank may be provided with inlet means for the liquid fraction in the form of a plurality of perforated pipes disposed along the bottom of the digester to ensure an equitable distribution of the liquid throughout the base of the digester. In an alternative arrangement the matrix is carried on a perforated plate disposed horizontally a short distance above the floor of the digester and the liquid is fed to the space between the floor and said plate and caused to percolate upwardly through the plate and the matrix carried on the plate.

Some embodiments of the invention are hereinafter described with reference to the accompanying drawings, wherein:

Figure 1 is a diagrammatic side elevation of one embodiment of apparatus according to the invention;

Figure 2 is a side elevation of a second embodiment of a methane digester according to the invention;

Figure 3 is a sectional elevation on the line A—A of Figure 1;

Figure 4 is a plan view of the digester of Figure 1; and

Figure 5 is a plan view of the floor of the digester of Figure 1.

Referring to Figure 1 of the drawings, animal waste from a piggery or the like is collected in a primary reactor cum sedimentation tank 1 where it is diluted, if necessary. The slurry is retained in tank 1 for several days to allow fermentation to occur and to permit the solids fraction to settle. The supernatant which contains the volatile acids formed in the fermentation process is pumped by a pump 2 from the holding channel 1 through a pipe 3 and into the bottom of an anaerobic digester 4 by means of a plurality of perforated pipes 5 spaced apart along the floor of the digester.

The anaerobic digester 4 is a tank of rectangular, rhombic or circular cross-section, suitably constructed from sheet steel. In the digester a holding matrix 6 is used to act as a support for attached and confined microbial flocs which carry out the methanogenesis. This matrix may be stone, plastics, anthracite or other suitable material. Limestone pebbles or gravel has been found suitable. Feeding the digester from the base ensures equitable distribution of the feed liquid through the reactor and adequate mixing. Preferably, the side walls of the tank are provided at spaced intervals with dispersion rings in the form of flanges 7 which prevent short circuiting of the liquid up along the surface and the side walls. The head space 8 permits the separation of methane gas from the treated effluent. The gas may or may not be collected in a separate gas storage tank 9. Alternatively the gas storage tank may be part of the reactor using a floating lid 10 as shown in the drawings. The floating lid 10 is in the form of a rectangular box-like structure open at the bottom and which is preferably fabricated from sheet steel. The lower peripheral edges 11 of the side walls of the lid 10 are located in a channel 12 which runs around the inner top edge of the digester tank 4. The channel 12 is, in effect, a weir over the edge of which the treated effluent from the digester flows. The liquid effluent is removed from the channel 12 through an outlet 13 the head of which can be adjusted to vary the gas pressure within the head space 7. The channel 7 also acts as a liquid seal to prevent escape of gas from around the lower periphery of the lid 10. The gas leaves the head space 7 through an outlet pipe 13 which may be connected to a gas meter (not shown) and, if desired, to the gas holder 9 or, alternatively direct to a gas burner. The liquid effluent from the digester is removed through pipe 14 and can be re-circulated to dilute strong wastes to the tank 1 or may be sprayed directly on land. Alternatively, as the liquid effluent leaves the digester at a temperature of about 35°C it can be used to heat a sludge drying unit 15. Settled sludge from the

tank 1 may also be fed to the drying unit 15 along pipe 16 or led off for disposal on land directly or in conjunction with the liquid effluent.

Methane is produced in the digester 4 by a group of an anaerobic bacteria which work in conjunction with a wider range of bacteria which are involved in the initial liquefaction of the farm wastes. As mentioned above the reaction is carried out in two stages. In the first stage, the organic matter contained in the effluent is converted to short-chained fatty acids, such as butyric, propionic, acetic and, possibly, formic acid with the associated gas production of CO_2 and hydrogen. Any reduction in total population load which occurs in this stage is brought about by the escape of CO_2 gas which is only produced in small quantities. In the second stage, the short-chained fatty acids are converted by the methane producing organisms to CH_4. This CH_4 is in gaseous form and it is in this stage that most of the COD (chemical oxygen demand) reduction occurs. Every gram of CO_2 removed is equivalent to 0.395 L of CH_4 gases. The reaction may be illustrated diagrammatically as follows:

WASTE MATERIAL

↓ Hydrolytic stage (exoenzyme catalysed)

Stage I — ORGANIC MONOMERS AND OLIGOMERS

↓ Fermentative stage

ACIDS, H_2, CO_2 (Ethanol)

(acetate, propionate, butyrate + smaller amounts of valeric, lactate, formate, etc.)

↓ Acetogenic stage

Stage II — ACETATE, H_2, CO_2

↓ Methanogenic stage

CH_4 + CO_2

Because of the limited number of bacterial species involved in the methanogenesis stage, fairly stringent environmental conditions are required before fermentation can take place or continue to occur. Preferably the acids entering the digester after stage I has been completed have a pH in the range 6.8 to 7.4 and are at a concentration of between 5,000 — 20,000 mg/l of acetic acid. Although the pH is preferably kept in the range specified it has been found that the process of the invention will operate reasonably satisfactorily with a pH in the range of 6 to 8 or where the method of the invention is used to treat dairy effluent, the pH may be in the range of 4 to 9.

The digester may be seeded with methane bacteria when first installed but thereafter it should not be necessary to add these bacteria again since the growth of these bacteria in the digester will maintain the population. The gas produced from anaerobic digesters, irrespective of the waste materials used, has a composition of 65 to 80% methane and 35 to 20% carbon dioxide. The calorific value of this methane is 5,700 to 7,000 kcal/m^3 (640 to 790 BTU/ft^3) which is almost comparable with bottled commercial gas. The gas can be used directly without further processing. With town waste 1 kg of destroyed organic matter gives 900 to 1,000 l of gas (1-lb. gives 14 to 16 ft^3). With such a waste 400 to 500 l gas are produced per kg or organic material entering the plant. With piggery slurry one gallon containing 1.1-lb. TS is produced per pig per day. It is believed that 5.63 ft^3 gas/pig/day or 5.63 ft^3 can be produced from a gallon of undiluted waste.

The methane forms at the top of the digester 4 and may be collected in a gas holder 8. A gas

holder capable of holding 20 to 40% of daily output may be used in large installations while nylon bags and a pressure pump to fill cylinders can be used for small installations. Assuming an output of 563 ft^3/day produced from 100 pigs, this would fill 3 bottles at 2,000 psi or 268 bottles at 30 psi.

Through the action of the holding matrix a high volume of methane bacteria is maintained and this, coupled with the fact that the temperature of the liquid in the digester is maintained at about 35°C, means that only about on average a 2 day retention time or less of the slurry in the digester is required. This is in contrast with a retention time of 10 to 12 days with known high-rate digesters where heat is used, and with a retention time of several months with known digesters operated at ambient temperatures (i.e. of 10 to 15°C). In view of the shorter retention period the digester may have, for example, a capacity of 2,000 to 3,000 gallons as compared to a capacity of 10,000 to 15,000 gallons which would be required if the digester and the process were of the conventional kind. Thus, the method and apparatus of the invention is particularly suitable for farm use, particularly for use in piggeries, where a digester of a capacity of 2,000 to 3,000 gallons would be suitable for a 1,000 pig unit.

A portion of the methane produced is used to heat the slurry fed to the digester. Preferably the methane is fed to a gas-generator which heats water to about 60°C and this is circulated through heat-exchanger pipes 17. The digester and inlet and outlet pipes are, preferably, well insulated so as to reduce the amount of heat lost. The remainder of the hot water produced can be used to heat the sludge in the drying bed 15, and also to heat pig houses, farm dwelling and so on. In the case of a 100 pig unit it is envisaged that a digester of a volume of 400 gallons would be suitable. A digester of this capacity should yield about 563 ft^3 of gas or more per day, i.e. 337,800 BTU/day. Of this, some quantity, say one-third, would probably be required for heating, leaving 224,800 BTU/day available for other uses.

As mentioned previously, the liquid effluent from the digester and the solid fraction removed from the tank 1 are fed to a drying bed 15, which is provided with a polythene cover and, preferably, is heated above ambient temperature to accelerate drying of the sludge. Liquid effluent leaving the drying bed through pipe 18 is passed through sand filters. The BOD removal in the digester reduces the effluent concentration to such a level that after treatment by the sand filter it may be released safely into streams and rivers. The dried sludge can be used on its own as an organic fertiliser or mixed with other ingredients such as quicklime or dolomite to produce a good quality baggable fertiliser, or mixed with peat and trace elements to produce gardening composts. It is also envisaged that the dried sludge could be used as a feedstuff for pigs as it has a high nutrient content. Instead of drying the slurry it could be used in the damp state, after removal of excess liquid to the sand filter, as a fertiliser for land spreading.

A second embodiment of a digester according to the invention is illustrated in Figures 2 to 5 of the drawings. The digester comprises a cylindrical tank 20 which may be fabricated from sheet steel or other suitable material. The tank 20 is totally enclosed to provide an oxygen-free atmosphere. The top of the tank is provided with manholes 21 and 22 through which the bacteria-holding matrix may be placed in the tank. A third manhole 23 is located at the bottom of the tank. As best seen in Figure 3 a perforated floor 24 is provided in the interior of the tank and is located above the bottom of the tank to provide a space 25 beneath the floor 24. A bacteria-holding matrix in the form of, for example limestone chippings 26, of about $\frac{1}{2}$ an inch in diameter, is loaded on the floor 24 and forms the anaerobic filter material. An inlet pipe 27 enters the top of the tank and is disposed about the vertical axis of the tank. The inlet pipe 27 increases in diameter within the tank and leads to the space 25 beneath the perforated floor 24. In use, animal or other waste material in the form of a slurry is held in the holding tank 1 to permit fermentation to occur. The volatile acids produced are separated from the solid material and are fed through the pipe 27 into the space 25 and the liquid is caused to percolate upwardly through the matrix 26. An annular channel-shaped weir 28 is located near the top of the tank and after methaneogenesis has occurred the residual effluent overflows into the channel 28 and is drawn off through pipe 29. The pipe 29 is provided with a variable head so as to alter the pressure of the methane gas within the tank 20. The space 30 above the top of the weir 28 acts as a head-space for the methane formed in the methaneogenesis reaction. The gas is drawn off from this head-space 30 through a pipe 31 which leads to suitable gas-holding means or to a burner. A relief valve 32 is provided at the top of the tank to allow gas to escape if an excess pressure builds up within the tank. As mentioned previously, the effluent within the tank must be maintained at a temperature of about 35°C to allow the methaneogenesis to occur and for this purpose a heating coil 33 is provided in the tank immediately above the perforated floor 24. Hot water, or the like, may be circulated through the heating coil 33. The heating coil 33 is shown in plan in Figure 4 of the drawings.

The tank 20 is supported on feet 34 and the tank may be located either inside a building or outside. If located outside it is preferably suitably insulated. If desired a scum descaler (not shown) can be provided in the region of the top of the weir 28 to remove scum from the top of the tank.

The effluent removed from the tank through pipe 29 may be fed to a drying bed or to a sand filter as described in relation to Figure 1. If a high degree of COD removal is required the effluent can be treated by floculation. Suitable floculation agents are, for example, ferric chloride or polyelectrolyte.

CLAIMS

1. A method for treating waste products, particularly strong organic waste such as animal slurries, to produce methane comprises:

i) holding the slurry for a period of time necessary to allow for the fermentation and conversion of the organic fraction of the slurry to volatile acids;

ii) separating a liquid fraction containing said volatile acids from a solids fraction; and

iii) feeding said liquid fraction containing said volatile acids into an anaerobic methane digester which contains a bacteria-holding matrix.

2. A method as claimed wherein the liquid fraction is fed to the base of the digester and is caused to flow upwardly through said matrix in the digester.

3. A method as claimed in either of the preceding claims wherein the temperature of the liquid in the digester is maintained above ambient temperature.

4. A method as claimed in Claim 3, wherein the liquid in the digester is maintained at a temperature in the range of 25°C to 35°C.

5. A method as claimed in any of the preceding claims wherein the solid fraction separates from the liquid fraction by sedimentation and the supernatant containing the volatile acids is then fed to the digester.

6. A method as claimed in any of Claims 1 to 4, wherein the solid fraction is separated from the liquid fraction by mechanical separating means and the liquid fraction containing the volatile acids is then fed to the digester.

7. A method as claimed in any of the preceding claims wherein the liquid fraction fed to the digester has an acid concentration in the range 5,000 to 20,000 mg/l measured as acetic acid.

8. A method as claimed in Claim 7, wherein the liquid fraction has a pH in the range 6.8 to 7.4.

9. A method as claimed in any of the preceding claims wherein the liquid fraction contains some suspended solids.

10. A method as claimed in any of the preceding claims wherein the methane gas generated in the digester is separated from the residual effluent at the top of the digester.

11. A method as claimed in any of the preceding claims wherein the residual effluent withdrawn from the digester is passed through a sand filter.

12. A method as claimed in any of the preceding claims wherein the residual effluent withdrawn from the digester is treated with a floculation agent.

13. A method as claimed in any of the preceding claims wherein the liquid fraction of the slurry is dried in a drying bed.

14. A method as claimed in Claim 13, wherein the drying bed is heated by means of the residual effluent withdrawn from the digester.

15. Apparatus for use in the method claimed in Claim 1 which comprises slurry holding means in which fermentation of the slurry can occur, means for separating a liquid fraction of the slurry from a solids fraction, means for feeding the liquid fraction to an anaerobic filter which comprises a container having a holding matrix for microbial flocs, and means for removing methane gas and residual effluent from the anaerobic filter.

16. Apparatus as claimed in Claim 15, having inlet means for feeding the liquid fraction to the bottom of the filter and outlet means for the gas and residual effluent at the top of the filter.

17. Apparatus as claimed in Claim 16, wherein the inlet means for the liquid fraction comprises a plurality of perforated pipes disposed along the bottom of the filter through which the liquid fraction can be fed to the base of the filter.

18. Apparatus as claimed in Claim 15, wherein the container is in the form of a tank and is provided with a perforated floor spaced a short distance above the bottom of the tank and which carries the holding matrix, and wherein the inlet means leads to the space beneath the perforated floor such that the liquid fraction entering this space can percolate upwardly through the perforated floor and the holding matrix.

19. Apparatus as claimed in any of the preceding claims wherein the container is provided adjacent the top thereof with a channel-shaped weir over which the residual effluent flows and which is connected to an outlet pipe for the effluent.

20. Apparatus as claimed in Claim 19 in which the channel-shaped weir extends around the inner walls of the filter and the filter is provided with a floating cover the lower peripheral edges of which are located in the channel such that the effluent in the channel acts as a liquid seal to prevent gas stored within the lid from escaping from the lid.

21. Apparatus as claimed in Claim 19, wherein the container has a fixed cover and the channel-shaped weir is disposed centrally of the container about an inlet pipe for the liquid fraction which enters the top of the container and is positioned along the vertical axis of the container.

22. Apparatus as claimed in any of Claims 19 to 21 wherein the outlet pipe for the residual effluent has an adjustable head whereby the gas pressure within the container may be varied.

23. Apparatus for treating waste products to produce methane substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

24. Apparatus for treating waste products to produce methane substantially as hereinbefore

described with reference to Figures 2 to 5 of the accompanying drawings.

25. A method for treating waste products to produce methane substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

26. A method for treating waste products to produce methane substantially as hereinbefore described with reference to Figures 3 to 5 of the accompanying drawings.

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